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Identifying Old Tidal Dwarf Irregulars

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ABSTRACT

We examine the observational consequences of the two possible origins for irregular galaxies: formation from collapse of a primordial cloud of gas early in the age of the Universe, and formation from tidal tails in an interaction that could have occured any time in the history of the Universe. Because the formation from tidal tails could have occurred a long time ago, proximity to larger galaxies is not sufficient to distinguish tidal dwarfs from traditional dwarfs. We consider the effects of little or no dark matter on rotation speeds and the Tully-Fisher relationship, the metallicity-luminosity relationship, structure, and stellar populations. From these selection criteria, we identify a small list of dwarf irregular galaxies that are candidates for having formed as tidal dwarfs.

Subject headings: galaxies: irregular — galaxies: formation — galaxies: evolution — galaxies: interacting

1. Introduction

Models of interacting galaxies have shown that tidal forces in the interaction can produce long tails of stars and gas that have been pulled out of the interacting galaxies (Toomre & Toomre 1972). Zwicky (1956) pointed out the possibility that self-gravitating objects might develop in these tidal tails that could then evolve into small galaxies. Since then, concentrations of stars and gas that are probable "tidal dwarfs" in the making have been observed at the tips of tidal tails in several interacting systems (for example, the Antennae system; Mirabel et al. 1992). Numerical modelling confirms that bound, galaxy-sized clumps can form in tidal tails (Barnes & Hernquist 1992; Elmegreen, Kaufman, & Thomasson 1993).

These tidal dwarfs, once the tidal tail itself has dispersed and the parent galaxies have moved off, could bear a striking resemblance to small, independent, Im-type galaxies (Schweizer 1974). The tidal dwarfs are small, gas-rich, morphologically disorganized, and already have on-going star formation (see also Mirabel, Lutz, & Maza 1991). Furthermore, the properties measured for tidal

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dwarfs are well within the range of properties seen for normal, relatively isolated irregular galaxies (Mirabel, Dottori, & Lutz 1992; Duc & Mirabel 1994; Hibbard et al. 1994; Hunter 1997).

Gravitational interactions are an on-going process in the Universe that began when galaxies themselves first formed. Therefore, this mechanism for forming irregular galaxies has been taking place for the age of the Universe. Hunsberger, Charlton, & Zaritsky (1996), for example, estimate that as many as one-half of the current dwarf galaxy population of compact groups may have been formed from the interactions of giant spiral galaxies. The formation of dwarf irregulars in compact groups is accelerated because of the increased crowdedness and potential for interactions there. However, interactions can and do occur outside of compact groups of galaxies as well.

One must then consider that any given dwarf irregular galaxy, including field galaxies, could have been formed in one of two ways: traditional formation from collapse of a primordial cloud of gas early in the age of the Universe, and tidal dwarf formation from an interaction of larger galaxies at any time during the history of the Universe. Because the time scale since the formation of a tidal dwarf can be large, a tidal dwarf could appear to be relatively isolated if the formation took place many Gyrs ago.

Because the formation mechanism of traditional dwarfs and of tidal dwarfs are different, some key characteristics of these two groups of galaxies could also be different, as outlined by Barnes & Hernquist (1992) and Elmegreen et al. (1993). In this paper we examine a sample of irregular galaxies with these observational differences in mind and ask whether any seemingly normal Im galaxy might be a candidate for an old tidal dwarf. The observational characteristics of Im galaxies and distinctions with tidal dwarfs are too imprecise at this time to do more than point out candidate tidal dwarf systems, but it is a way to begin thinking about the issue that not all irregulars may have had the same initial conditions.

Dwarf galaxies, galaxies that are intrinsically not luminous, come in a variety of types, including spirals, irregulars, ellipticals, and spheroidals, and Gerola, Carnevali, & Salpeter (1983) suggested galaxy interactions as a means for forming dwarf ellipticals. However, the most common type of dwarf is a gas-rich Im galaxy, and we will primarily concentrate on irregulars in this discussion.

2. Selection Criteria for Old Tidal Dwarfs

Since tidal dwarfs form from material drawn out of larger galaxies, their properties could differ significantly from those of traditional dwarf galaxies. Barnes & Hernquist (1992) suggest that tidal dwarfs formed from parent galaxies with dark matter distributed in extended massive haloes (Barnes 1992) will have $<5\%$ of the dwarf's mass in dark matter. Thus, tidal dwarfs should have low mass-to-light ratios. Tidal dwarfs may also have unusual metal abundances since they were made from material first processed in a much larger galaxy. Elmegreen et al. (1993) have also suggested that the age distribution of their stellar populations may also be peculiar since there will be old stars from the spiral along with stars that have formed in a burst of star formation when the dwarf first formed and stars that have formed at a much slower pace since then.

Some of these properties, like the amount of dark matter, will not depend on how long ago the tidal dwarf formed but others will. Tidal dwarfs forming out of modern day spirals are observed to be metal-rich because they have formed out of material already processed in a giant spiral (Duc & Mirabel 1999, Hunsberger et al. 2000); most dwarf irregulars today, on the other hand, are metal poor compared to all but the extreme outer parts of spiral disks. However, a tidal dwarf that formed from a spiral many Gyrs ago when spirals were still metal poor ($\geq$6 Gyrs ago for material drawn from the central regions of a galaxy like M33, $\geq$9 Gyrs ago for a galaxy like the Milky Way [Mollá, Ferrini, & Díaz 1997]). could have a metallicity today that is consistent with that of traditional, metal-poor dwarfs.

Another problem comes in disentangling evolutionary effects from initial conditions. For example, a galaxy which underwent a strong burst of star formation several Gyrs ago might be a tidal dwarf that formed then or it could be a tiny galaxy with a peculiar star formation history. We do know that many irregulars evolve with star formation rates that vary in amplitude by factors of a few, as would be expected in small galaxies (Ferraro et al. 1989; Tosi et al. 1991; Greggio et al. 1993; Marconi et al. 1995; Gallart et al. 1996a,b; Aparicio et al. 1997a,b; Dohm-Palmer et al. 1998, Gallagher et al. 1998, Gallart et al. 1999). However, others show evidence of higher amplitude variations either currently or in the past, some of which may be statistically significant (Israel 1988, Tolstoy 1996, Dohm-Palmer et al. 1997, Greggio et al. 1998, Tolstoy et al. 1998). Why statistically large variations occur in some seemingly isolated irregulars and not in others is not clear although arguments have been made that tiny galaxies should evolve via periodic starbursts (see, for example, Gerola, Seiden, & Schulman 1980). Clearly, we do not understand how irregular galaxies evolve well enough yet to be able to say whether a particular evolutionary history can only be consistent with a tidal dwarf formation scenario.

With these problems in mind, we examine properties of tidal dwarfs that are potentially different from those of traditional dwarfs. We are asking the question: Do any normal Im galaxies that we know of have properties that are consistent with a tidal dwarf origin?

Tidal dwarfs observed currently at the ends of tidal tails have M_B of -14 to -19 (Mirabel et al. 1992; Duc & Mirabel 1994; Hibbard et al. 1994), and a luminosity function of tidal dwarfs in compact groups extends to as bright as -18 in M_R (Hunsberger et al. 1996, converted to $H_0 = 65$ km s^{-1} Mpc^{-1}). An older tidal dwarf, however, might have faded from the glory days of formation. Therefore, we expect to find tidal dwarfs with $M_B > -18$. In Table 1 we keep a running list of dwarfs that stand out in the properties discussed below as possible tidal dwarf candidates.

2.1. Lack of Dark Matter

Barnes & Hernquist (1992) found that two interacting galaxies with extended massive dark haloes produced tidal dwarfs with <5% of its mass in dark matter. (How this property might be effected by a different distribution of dark matter in the parent galaxies is not explored.) This lack of dark matter in tidal dwarfs is potentially the most useful distinguishing feature since that property will not change with time and it does not depend on when the dwarf formed. Most disk galaxies have rotation curves that require the presence of dark matter, and some studies of irregulars have argued that irregulars are just as dominated by, or even more dominated by, dark matter than spirals. Here we look for signs of unusual dark matter properties among irregulars through rotation curves and the traditional Tully-Fisher relationship.

Rotation curves of irregular galaxies are a mixed bag. There are those that look like normal disk rotation curves: they rise as a solid body, peak, and level off or even begin to fall (for example, DDO 154: Carignan & Purton 1998). In other irregulars the rotation curve rises but never peaks, presumably because the rotation curves have not been observed far enough out.

However, there are also irregulars that have been found to have no measureable rotation with upper limits on $V_{rot,max}\sin i$ of $\leq$7.5 km s^{-1}. These include DDO 69 (=Leo A; Young & Lo 1996), DDO 99, DDO 120, DDO 143 (Swaters 1999), DDO 155 (=GR 8; Lo, Sargent, & Young 1993; but see also Carignan, Beaulieu, & Freeman [1990] who interpret the velocity field as having some rotation in the inner 250 pc); DDO 187 (Swaters 1999), DDO 210, DDO 216 (=Pegasus Dwarf), LGS3 (Lo, Sargent, & Young 1993); Sag DIG (Young & Lo 1997), and NGC 4163 (Swaters 1999). This is in contrast to low surface brightness spirals that, in spite of their very low surface brightness levels, nevertheless, rotate at high speeds compared to irregulars (de Blok, McGaugh, & van der Hulst 1996). Galaxies with no measureable organized rotation may be good candidates for no dark matter.

The maximum rotation speeds of irregulars and a sample of spirals taken from Broeils (1992) are shown in Figure 1. Upper limits to the rotation speed are used to put the galaxies with no measureable rotation on this plot. One can see that at an M_B of about −15 and fainter the irregular galaxies deviate strongly from the relationship between M_B and $V_{rot,max}$ determined for spirals. The deviation from the relationship is in the sense that many irregulars have rotation speeds that are too small for their luminosity. This is in the sense that one expects for galaxies that have too little dark matter.

In a study of dark matter in late-type dwarf galaxies, Swaters (1999) has shown that there may not be a lot of dark matter in the disks of irregulars, but dark matter in haloes is still required to explain the rotation curves. However, in some galaxies the evidence for any dark matter at all is not strong (for example, NGC 1569: Stil 1999). Swaters (1999) found 5 galaxies in his study, including 3 Ims (DDO 50, DDO 125, DDO 143), for which a maximum disk fit to the rotation curve leaves no room for dark matter. He suggests that one of these galaxies, DDO 125, is a good candidate for a tidal dwarf since it lies near giant HI streamers associated with the larger irregular galaxy NGC 4449 (Hunter et al. 1998).

In Figure 2 we consider an alternative means of looking at the mass, and hence dark matter, in galaxies: the traditional Tully-Fisher relationship (Tully & Fisher 1977). The Tully-Fisher relationship is shown in Figure 2a where we plot log W_{20}^{ci} against M_B^i. W_{20}^{ci} is the full width at 20% intensity of the integrated HI profile, corrected for instrumental broadening, random motions, and the inclination of the galaxy (Broeils 1992). The inclinations were determined using minor-to-major axis ratios from Swaters (1999) and de Vaucouleurs et al. (1991,=RC3) and assuming an intrinsic ratio of 0.3 (Hodge & Hitchcock 1966, van den Bergh 1988). The M_B^i have been corrected for internal absorption, also dependent on the galaxy inclination, according to Broeils (1992) with a reduction of a factor of 4 in the absorption compared to spirals to better match the observed lower dust contents of irregulars. W_{20}^{ci} should measure approximately twice the maximum rotation speed and so should be related to the total mass in the galaxy. This plot has the advantage over the plot shown in Figure 1 that integrated HI profiles are available for far more galaxies than are velocity fields. We see that there is much more scatter among the irregular galaxies than the spiral sample, but the scatter for the brighter irregulars is distributed around the relationship defined by the spirals with more falling below the relationship than above it. However, at the low end of the relationship—low HI widths and low luminosities, several irregulars are too bright for their HI widths. This deviation above the relationship is consistent with the possibility that those galaxies have less dark matter than other galaxies of that luminosity although statistics on low luminosity galaxies are poor.

Carignan & Beaulieu (1989), Swaters (1999), and McGaugh et al. (2000) have observed that the Tully-Fisher relationship begins to break down for low luminosity galaxies although the galaxies in their samples deviate in the sense of being underluminous for their rotation speed. Milgrom & Braun (1988) suggest that the relationship is maintained if M_B^i is replaced with the total luminous mass, including gas. We have examined this possibility in Figure 2b. We have estimated the mass in stars from M_B^i and a stellar mass-to-light ratio that is appropriate for a galaxy forming stars at a constant rate for 10 Gyr with a normal stellar initial mass function (Larson & Tinsley 1978). This is clearly a rough approximation and will not apply equally well to all of the galaxies in the sample. However, this is most likely to break down for the dwarf galaxies for which errors of factors of even 10 in stellar mass will not make very much difference to the mass in gas plus stars because the masses are usually dominated by the gas. The mass in gas is HI plus He ($1.34\times M_{HI}$) and does not include molecular gas since this quantity is not known for most irregulars. The resulting relationship looks similar to that in Figure 2a, and, if one compares equal logarithmic intervals, the scatter is no less. This is in contrast to what McGaugh et al. (2000) found: that galaxies with $W_{20}^{ci} < 180$ km s^{-1} in their sample, that extends to a mass of 10^7 $M_\odot$, are brought into agreement with spirals once the gas content is taken into account.

In Figure 2b we see that only a few galaxies deviate more than most irregulars. Several, such as DDO 155, NGC 4163, and the Sm galaxy DDO 135, fall below the relationship for the rest of the galaxies. This is in the opposite sense of what we are looking for. Of those galaxies above the relationship, only IC 1613, DDO 210, DDO 216, and SagDIG, because they are upper limits (all but IC 1613 have no measureable rotation), have the potential to fall further outside the relationship than the bulk of the galaxies. (We ignore the spiral DDO 80, possibly interacting, discussed by Broeils [1992].)

2.2. Metallicity

At the time of formation the tidal dwarf will take on the metallicity of the material drawn from the parent spiral, and, since spirals have evolved more rapidly than irregulars, this could make the tidal dwarf more metal rich (Schweizer 1978). In fact, many tidal dwarfs in formation observed today are too metal rich for their luminosity (Duc & Mirabel 1997, Hunsberger et al. 2000). For normal irregulars, Richer & McCall (1995) found that the scatter in the metallicity-luminosity relationship increases for galaxies with $M_B > -15$. This could imply that low luminosity galaxies have a more diverse evolutionary background. We have examined the position of irregular galaxies on a plot of oxygen abundance versus M_B, adapted from Hunter & Hoffman (1999). In Figure 3 we show the oxygen abundance plotted against M_B for a sample of spiral and irregular galaxies along with Richer and McCall's relationship for low-luminosity galaxies. The scatter even among the spirals is substantial. Although most of the irregulars with no measureable rotation deviate substantially from the relationship, the scatter among all of the galaxies is too high to be able to say that they deviate more than most. Clearly the lower luminosity end of this relationship needs to be explored further.

We have also included a few Im galaxies in the Virgo cluster for comparison. Potentially the higher density of clusters like Virgo will result in a higher population of tidal dwarfs as has been found in compact clusters (Hunsberger et al. 1996). Vílchez (1995) had suggested that irregulars in Virgo are in fact more metal rich than field irregulars, but he assumed the high metallicity branch of the double-valued relationship between emission-line ratio and abundance. On the other hand, Lee, McCall, & Richer (1998) found metallicities for Virgo irregulars that are consistent with the relationship. In our plot, where we assumed the lower branch of the metallicity, the Virgo Cluster galaxies do not stand out from the general scatter.

However, there are also complications to using metalliciy as a tidal dwarf indicator: 1) If the material that forms the tidal dwarf comes primarily from the outer part of the spiral, it could be just as metal poor as an irregular. 2) If a tidal dwarf formed many Gyr ago, the starting metallicity would be lower than if it had formed today. 3) The metallicity will change as the dwarf evolves and how it changes is convolved with how it evolves. 4) There are substantial observational uncertainties in determining the oxygen abundance.

2.3. Structure

Irregular galaxies are generally believed to be disk systems, although thicker than spirals Hodge & Hitchcock 1966, van den Bergh 1988). However, there is some debate about even this basic property of irregulars (Sung et al. 1998). However, we see no reason why a dwarf formed in a tidal tail would have to be a disk. Furthermore, the irregulars that have no measureable disk rotation could be ones that are not disk-shaped. Intriguingly, Patterson & Thuan (1996) examined the surface photometry and scale lengths of a sample of dwarf irregular galaxies and found that they divided into two groups. One group has scale lengths like those of dwarf ellipticals and twice those of BCDs, and the other is comparable to BCDs and half that of dEs. Could these two groups also be related to the two origins? At this point, we cannot tell which group would be the tidal dwarfs. In addition, studies of the irregulars WLM and NGC 3109 have shown that those irregulars have a halo of old stars in addition to their disk (Minniti & Zijlstra 1996; Minniti, Zijlstra, & Alonso 1999). They point out that by contrast all of the old stars in the LMC are in its disk. However, whether this is normal or abnormal for irregulars is not yet clear.

2.4. Stellar Population

Another possible oddity of a tidal dwarf is its stellar population. Elmegreen et al. (1993) argue that the tidal dwarf should consist of a small fraction ($\leq$40%) of old stars from the parent spiral, a strong starburst at formation, and a normal distribution of mixed ages of stars formed since the galaxy's formation. Unfortunately, not many color magnitude diagrams of irregulars go deep enough for analysis to pull out limits on star formation histories more than a few Gyrs into the past. Of those that can put some limits up to 10 Gyrs ago, 6 galaxies appear to have normal star formation histories (DDO 216: Aparicio, Gallart, & Bertelli 1997a; LGS3: Aparicio et al. 1997b; IC 1613: Cole et al. 1999; NGC 3109: Minniti et al. 1999; NGC 6822: Gallart et al. 1996a; WLM: Minniti & Zijlstra 1997). However, one galaxy may fit the pattern expected of a tidal dwarf: DDO 69. Tolstoy et al. (1998) put a limit of $<$10% of the total in a very old stellar population, with the majority of the star formation taking place within the past 1.5 Gyr. In the scenario of Elmegreen et al., DDO 69 would have formed about 2 Gyrs ago.

3. Discussion

We have examined properties of a sample of irregular galaxies from the perspective of features that might distinguish galaxies formed in tidal interactions at some time shorter than a Hubble time from those formed from collapse of a primordial gas cloud a Hubble time ago. We have considered the lack of dark matter predicted by models as manifested in rotation speeds and the Tully-Fisher relationship, the fact that tidal dwarfs may have formed from enriched material, structure, and peculiar stellar populations. However, using these features to identify old tidal dwarfs is currently imprecise. Abundances and star formation histories are entangled in other evolutionary and observational effects, and not enough is known about the amount and location of dark matter and the true structure of irregulars.

Nevertheless, we have identified candidates for old tidal dwarfs, and they are listed in Table 1. We have also listed the distance to the nearest large galaxy. A little over one-quarter of the galaxies in this list are in the Local Group. Eighty-five percent of the galaxies are within 0.5 Mpc of a large galaxy; and one lies near supergiant gas streamers wrapped around a nearby Im galaxy.

Because of the difficulties in identifying old tidal dwarfs, these galaxies can only be considered candidates at this point. In addition this is not an exhaustive list, and we have not included representative samples of other groups of dwarfs including dwarf ellipticals and dwarf spheroidals. The peculiar galaxy IZw18, for example, has the peculiar stellar populations and complex kinematics that might make it a candidate.

Clearly, it is important to understand the formation and evolutionary processes of the most common galaxy in the universe: irregular and other dwarf galaxies. The fact that irregulars could potentially be formed in more than one way complicates our ability to interpret the properties of the galaxies that we see today. How can we improve our understanding of irregulars so that differences due to different origins might be more apparent? We need to better understand the kinematics and structures of irregular and dwarf galaxies. This includes the gas and stellar kinematics and velocity dispersions from which we can infer the distribution and amount of dark matter and the stellar structure of the galaxy. We also need more very deep studies of stellar populations of irregulars, particularly probing the extremes of galaxy characteristics. Only once there is a statistically significant sample of star formation histories can we begin to see trends. Finally, we need numerical simulations that can show whether interactions are feasible, perhaps between two unequal mass partners, that can produce a tidal dwarf and still leave the parent spiral intact. This is particularly important for the Local Group system in which we identify 6 candidate old tidal dwarfs, but the obvious parents are relatively normal looking spirals.

This discussion originated while EWR was a summer student at Lowell Observatory under the Research Experiences for Undergraduates program operated by Northern Arizona University and funded by the National Science Foundation under grant number 9423921. Support for this work was provided by the Lowell Research Fund and the Friends of Lowell Observatory.

Table 1. Candidate Old Tidal Dwarfs.

Galaxy	Rotation[a]	T-F[b]	Stellar Pop	Nearest Large Galaxy Δd (kpc)	Nearest Large Galaxy ΔV (km/s)
DDO 43	N	Y	...	690	82
DDO 50	Y	N	...	510	190
DDO 52	N	Y	...	710	50
DDO 69	Y	Y	Y	Local Group	
DDO 99	Y	Y	...	380	1
DDO 120	Y	Y	...	70	73
DDO 125	Y	Y	...	41	10
DDO 143	Y	N	...	320	160
DDO 155	Y	N	N	68	53
DDO 165	N	Y	...	260	37
DDO 187	Y	Y	...	2500	150
DDO 210	Y	Y	...	Local Group	
DDO 216	Y	Y	N	Local Group	
CVndwA	Y	...	...	250	12
Haro 4	N	Y	...	170	35
IC 1613	...	Y	N	Local Group	
LGS3	Y	N	N	Local Group	
M81dwA	...	Y	...	500	150
NGC 1569	Y	N	...	240	135
NGC 4163	Y	Y	...	95	79
Sag DIG	Y	Y	...	Local Group	

[a]Galaxies that deviate significantly from the relationship in Figure 1.

[b]Galaxies that potentially deviate from the relationship in Figure 2.

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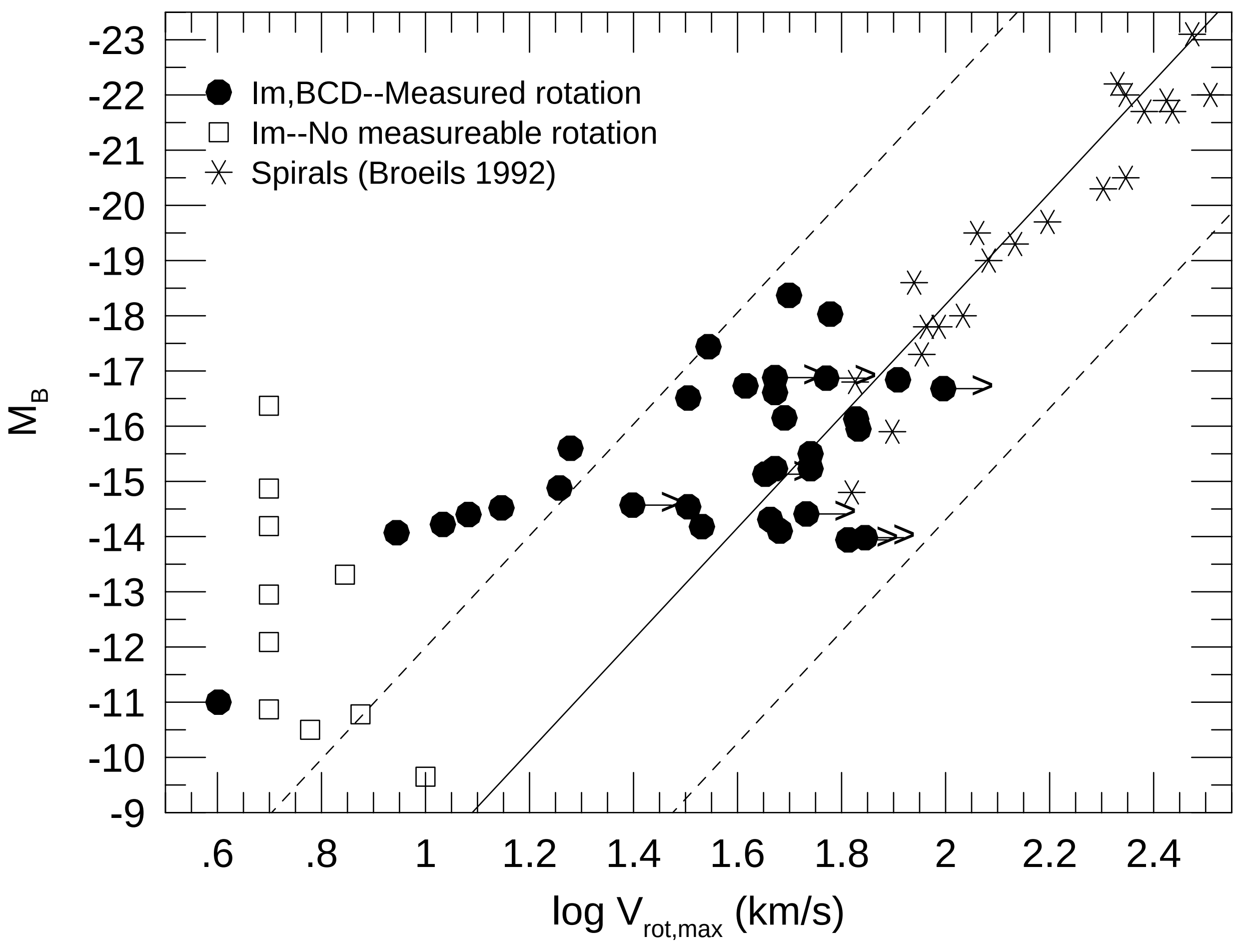
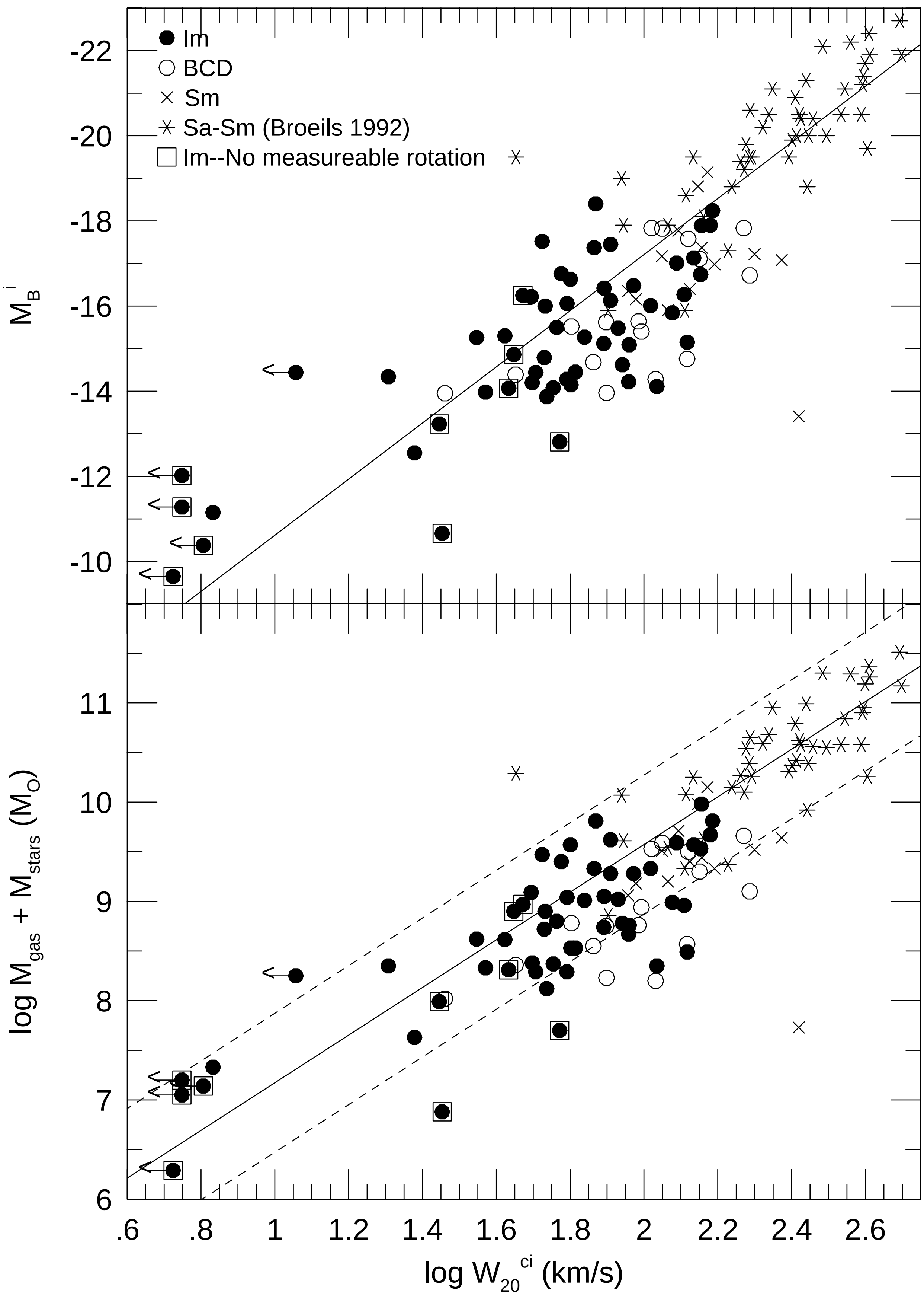
Fig. 1.— Maximum rotation speed plotted against absolute blue magnitude. Arrows pointing to the right are lower limits to the maximum rotation speed because the rotation curve was not observed to level off. Open squares are upper limits to the rotation speed because no rotation was measured. The spiral galaxies are from Broeils (1992), as is the solid line fit to the spirals (modified for an H_0 of 65 km s^{-1} Mpc^{-1}). The dashed lines are the solid line offset 3.9 magnitudes in M_B, enough to encompass the bulk of the scatter around the solid line. M_B for the Im and BCD galaxies was corrected for internal absorption assuming an $E(B-V)_i$ of 0.05. Foreground absorption is taken from Burstein & Heiles (1984) with the extinction curve of Cardelli, Clayton, & Mathis (1989). The rotation data for irregulars are taken from Sargent, Sancisi, & Lo (1983); Comte et al. (1986); Skillman et al. (1988); Carignan & Beaulieu (1989); Lake & Skillman (1989); Jobin & Carignan (1990); Broeils (1992); Puche et al. (1992); Lo, Sargent, & Young (1993); Simpson (1995); Young & Lo (1996, 1997); Broeils & Rhee (1997); McIntyre (1997); van Zee et al. (1997); Wilcots & Miller (1998); Stil (1999); Swaters (1999); and Hunter, Elmegreen, & van Woerden (2000).

Fig. 2.— W_{20}^{ci} is the full width of the integrated HI profile at 20% intensity, corrected for instrumental broadening, random motions, and inclination of the galaxy (Bottinelli et al. 1990, Broeils 1992). W_{20}^{ci} is approximately twice the maximum rotation speed of the HI gas in the galaxy and so is related to the total mass of the galaxy. Those galaxies for which the correction for random motions is larger than the observed W_{20} are assigned a W_{20}^{c} of 5 km s^{-1} and then corrected for inclination. They are shown as upper limits. a) Upper panel: The solid line is the relationship for spirals from Broeils (1992) converted to an H_0 of 65 km s^{-1} Mpc^{-1}. b) Bottom panel: The mass in gas is taken to be 1.34 times the mass in HI, to account for He. The mass in stars is 1.54 times the blue luminosity in solar units. The solid line is our least squares fit to the spirals. The dashed lines are the solid line offset 0.7 in the logarithm of the mass, enough to encompass the bulk of the scatter around the solid line.

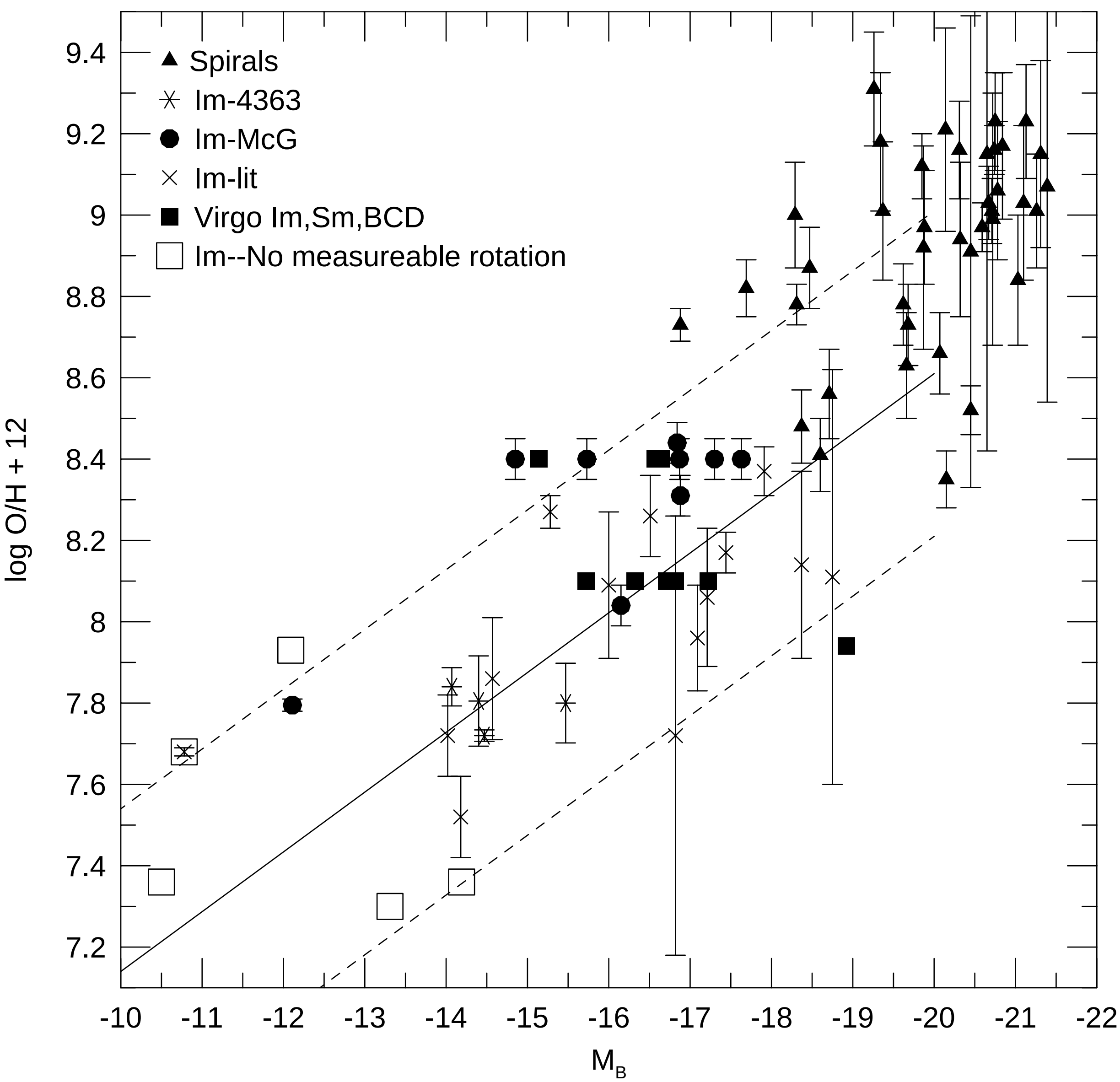
Fig. 3.— Figure adapted from Hoffman & Hunter (1999) with a few Virgo irregulars and irregulars with no measureable rotation included. Data for the Virgo irregulars are taken from Gallagher & Hunter (1989) and Vílchez (1995) and rederived with the assumption that the oxygen abundance is the lower of the two possibilities for the emission-line ratios. The solid line is the relationship derived by Richer & McCall (1995) for low luminosity galaxies. The dashed lines are the solid line offset 0.4 dex in log O/H+12, enough to encompass the bulk of the scatter around the solid line. Spirals are from Zaritsky, Kennicutt, & Huchra (1994). Except for the spirals, galaxies are distinguished in the plots by the method used to estimate O/H: The label "4363" means that the determination of O/H was from use of [OIII]λ4363 to determine T_e, "McG" refers to the method of McGaugh(1991), and "lit" refers to values taken from the literature. We have left off measurements determined by the method of Edmunds & Pagel (1984) that has a higher uncertainty. M_B for the non-spiral galaxies was corrected for internal absorption assuming an $E(B-V)_i$ of 0.05. Foreground absorption is taken from Burstein & Heiles (1984).



Im,BCD--Measured rotation
Im--No measureable rotation
Spirals (Broeils 1992)
M_B
log $V_{rot,max}$ (km/s)
-23
-22
-21
-20
-19
-18
-17
-16
-15
-14
-13
-12
-11
-10
-9
.6
.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4



Im
BCD
Sm
Sa-Sm (Broeils 1992)
Im--No measureable rotation
M_B^i
$\log M_{gas} + M_{stars}$ (M_O)
$\log W_{20}^{ci}$ (km/s)



Spirals
Im-4363
Im-McG
Im-lit
Virgo Im,Sm,BCD
Im--No measureable rotation
log O/H + 12
9.4
9.2
9
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20
-21
-22
M_B